

Design of a 1.5-m, 32-GHz, Clear Aperture Antenna

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Present DSN ground station antennas are of the symmetric dual-reflector type. In the last few years, an investigation has been made of alternative ground station antenna designs which have a clear aperture (no subreflector or strut blockage) and shaped reflector surfaces. In FY82, a 1.5-m, 32-GHz clear aperture antenna model will be built for experimental studies. This article describes the underlying considerations leading to the determination of the parameters defining the model antenna geometry. Detailed analysis of the model electrical characteristics will be reported at a later time.

I. Introduction

Present DSN ground station antennas are of the symmetric Cassegrainian dual reflector type. In the last few years, an investigation has been made of alternative ground station antenna designs which have a clear aperture (no subreflector nor strut blockage) and shaped reflector surfaces. The new configurations are shown to have a potential 2 to 3 dB G/T (gain/noise temperature ratio) performance enhancement compared to the present symmetric reflector stations (Ref. 1). Figure 1 affords a schematic illustration of the new antenna under study along with a conventional Cassegrain.

Significant advances in the synthesis, analysis and performance optimization of this new type of antenna have been accomplished since the investigation was initiated in 1978. Parallel studies on the structural design of asymmetrical reflectors were undertaken in the same period. With this much theoretical development, a new task to design, fabricate and test a 1.5-m clear aperture antenna model was started in FY81. The goal is to provide experimental verification of the predicted superior performance of the new antenna design.

This article describes the underlying considerations leading to the determination of the parameters defining the antenna geometry. We will start by describing briefly the reflector synthesis and analysis techniques used in the design process.

II. Optical Synthesis of the Offset Dual Shaped Reflector—the First Design Iteration

An approximate synthesis of the offset dual-shaped reflector problem based on ray optics laws was developed in 1979 (Refs. 2, 3). The geometry of the problem is shown in Fig. 2. In an exact synthesis, main and subreflector surfaces which convert a spherical wave emanating from the feed to a planar wave with prescribed amplitude and phase distribution in the main reflector aperture are generated. In our approximate approach, the output reflector aperture amplitude distribution has a small deviation from the prescribed distribution although the aperture phase distribution always follows the prescribed one exactly (generally a uniform phase distribution is desired).

There are a number of input parameters in the synthesis theory, Z_0 , R_0 , ρ_M , A , Ω and θ_M , as shown in Fig. 2. These parameters provide the flexibility to determine a preliminary configuration with desirable main-to-subreflector-diameter ratio and relative dislocations between the feed, the subreflector and the main reflector. In this iteration, additional input parameters p , ρ_{MM} , n (see following) are held to constant values.

The parameter n is used in the synthesis to specify a tapered input feed illumination of the form

$$I(\theta) = \cos^{n-1} \theta \quad (1)$$

In practice, the value $n = 85$ at which $I(\theta)$ approximates the pattern of a corrugated horn best is used in the first iteration.

A particularly interesting form of output aperture energy distribution is

$$V(\rho) = \left(1 - \frac{\rho^2}{\rho_{MM}^2}\right)^p \quad (2)$$

where $\rho_{MM} > \rho_M$ and $0 \leq p \leq 1$. The parameter $\rho_{MM} > \rho_M$ is introduced to avoid a mathematical singularity which would arise in the synthesis theory if ρ_{MM} in Eq. (2) is replaced by ρ_M . It has been found from experience that ρ_{MM} should be set to a fixed, nominally larger value than ρ_M . The value of the exponent p is arbitrarily fixed for the first design iteration; e.g., $p = 0$. Its value will be determined in a second iteration which enables one to select the optimal design based on the more accurate diffraction analysis (as opposed to optics). It is significant to note that changing the p value within its range 0 to 1 does not usually change the reflector geometry and surface profiles appreciably to necessitate new backup structure design. At the conclusion of the first design iteration, the basic geometry and dimensions of the antenna can be considered fixed. The design of the backup structure can be initiated concurrently with the second design iteration (diffraction design). Figure 3 shows a profile of the 1.5-m model obtained from this design cycle which was the basis for the initial mechanical and structural design.

III. Diffraction Analysis and Efficiency Computations—the Second Design Iteration

In this second iteration, we will analyze the diffraction characteristics and compute the efficiency of reflector designs corresponding to different p values in Eq. (2), holding the other reflector input parameters Z_0 , R_0 , etc. constant. Fig-

ure 4 shows an overview of this iteration cycle. Each efficiency term represents a loss mechanism within the antenna system. The overall antenna efficiency η_T is

$$\eta_T = \eta_{FS} \eta_{RS} \eta_P \eta_X \eta_I \eta_{RMS} \eta_C \quad (3)$$

The terms η_{RMS} and η_C are losses due to surface RMS error and dissipation in the antenna and feed. These are not included in the diffraction and efficiency analysis. In addition, one can obtain a first-order estimate of the antenna noise temperature at zenith from the rear spillover efficiency as

$$T_a = (1 - \eta_{RS}) \times 240 \text{ kelvins} \quad (4)$$

At the end of this iteration, we will have determined the final reflector profiles of an optimal gain or G/T design, the antenna efficiency (gain) and antenna noise temperature.

Note that Eq. (2) describes a nearly uniform aperture energy distribution with a taper near the aperture edge. It is not altogether apparent how an optimal gain or G/T design can result from specifying the particular aperture illumination function. In Refs. 4, 5, and 6 it is shown that this design strategy allows one to examine the tradeoff between a worsening illumination efficiency and an improving rear diffraction spillover efficiency as the illumination taper is increased (p increased) and arrive at an optimal design in gain or G/T.

IV. A Summary of Design Guidelines

For convenient reference, we provide the list below:

- (1) The feed is a corrugated horn with 22 dB gain.
- (2) The main and subreflector diameters are 1.5 and 0.45 m respectively.
- (3) The input parameters to the reflector synthesis program are $n = 85$, $p = 0.5$, $R_0 = 3.0$, $Z_0 = 0$, $A = 4.5$, $\rho_M = 3.0$, $\rho_{MM} = 3.000001$, $\theta_M = 16^\circ$, $\Omega = 0^\circ$.
- (4) Model test frequency is 32 GHz.
- (5) Reflector RMS surface tolerance is 0.2 mm.
- (6) Alignment accuracy between feed, subreflector and main reflector is 0.4 mm.

V. Feed for the Model

The feed design selected is that of a corrugated horn with an on-axis gain of 22 dB. The n -value at which $\cos^n \theta$ best approximates the corrugated horn power pattern in the least RMS error sense is found to be 85. A comparison of these two patterns is shown in Fig. 5a. The subreflector illumination

angle θ_M subtended at the feed is chosen to be 16° . At this angle, 96% of the feed radiated energy is intercepted by the subreflector; i.e., $\eta_{FS} = 0.96$. Although η_{FS} can be further improved by using a larger θ_M , this is attenuated by an expected lower phase efficiency η_p due to worsening variation in the feed phase pattern at larger angles (Fig. 5b). An iteration cycle to determine the optimal feed illumination angle θ_M and modification of the synthesis theory to incorporate arbitrary feed illumination pattern (instead of $\cos^n\theta$) were expected to yield at best token improvement and were not undertaken.

VI. The Reflector Design

The size of the subreflector diameter is the starting point of the reflector design. At the planned test frequency of 32 GHz, a 0.45-m subreflector is close to 50 wavelengths. This is considered to be of sufficient size for the optical laws, which form the foundation of the reflector synthesis theory, to be good approximations to diffraction theories. The main reflector diameter is 1.5 m, which corresponds to a main-to-subreflector-diameter ratio of 3.3 to 1. This ratio is lower than what one would normally use in a two-reflector system but is selected to hold down the fabrication cost. Note the input parameters R_0 , Z_0 , A , ρ_M and ρ_{MM} to the computer program, as given in Section IV, are dimensionless. These and the reflector surface coordinates generated by the program are scaled according to the reflector size. For example, in the case of the model design, the scale factor is 0.5 m, which brings $\rho_M = 3.0$ to $\rho_M = 1.5$ m.

The parameters Z_0 , R_0 , A , Ω , θ_M largely determine the relative dispositions of the feed, subreflector and main reflector. Care should be taken to ensure that a structurally acceptable and totally blockage-free package results from the choice of these. The feed tilt angle Ω is considered a less critical parameter in determining the model performance characteristics relevant to DSN operations and is set to 0° . Some evidences in the literature (Refs. 7, 8) suggest that this tilt angle may have a profound bearing on the polarization characteristics of offset dual reflectors. If the intended

usage of the antenna requires high polarization purity as in some earth orbit satellite ground stations, then an additional design iteration cycle determining the optimal feed tilt angle would be in order. In the DSN mode of operations, however, the primary figure of merit G/T is largely unaffected by the selection of this parameter, as the main effect of depolarization is a slight degradation in gain, on the order of 1% or less. This observation is supported by the diffraction and efficiency analysis which will be reported separately. With values of θ_M and Ω thus fixed, the first iteration involves varying input parameters Z_0 , R_0 and A only.

The parameter p , the exponent in Eq. (2), is determined from diffraction and efficiency analysis in the second design iteration to be 0.5, based on the optimal gain criterion. The computed aperture (or area) efficiency of the model is 86% exclusive of η_{RMS} and η_C .

The specified RMS surface tolerance of 0.2 mm is roughly one fiftieth of a wavelength at 32 GHz. It is believed that this tolerance and the specified alignment accuracy would limit the gain loss due to mechanical and structural imperfections to 2% or less. No firm guides can be found in the literature on how tight these tolerances should be. We are providing precision micrometer-type mounts for both the feed and the subreflector. These adjustments will allow us to peak up the antenna gain during tests and to study how antenna characteristics are affected by misalignment. Figure 6 shows the 1.5-m clear aperture antenna with its backup structure and a base plate. The whole assembly can be mounted on a standard antenna range pedestal for testing.

VII. Summary

The design of the 1.5-m clear aperture antenna has been presented. The procedure consists of two iterative cycles. In the first iteration, the geometry of the reflector is largely determined based on optics laws. In the second iteration, the optimal design is determined from the more accurate diffraction analysis. Detailed performance analysis will be reported in a future article.

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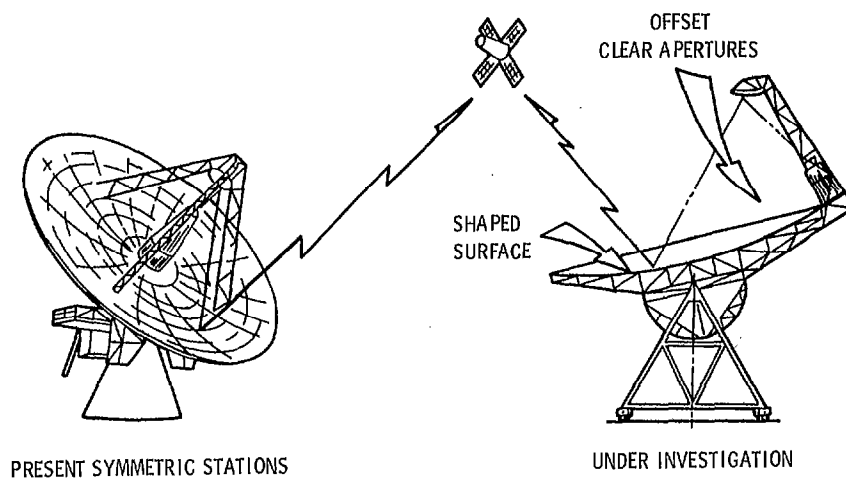


Fig. 1. Alternative reflector configurations for very low noise and high gain ground stations

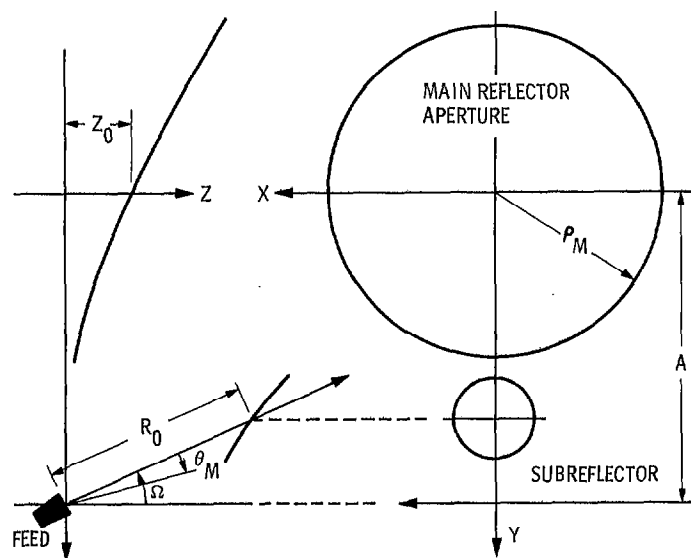


Fig. 2. Geometry of offset dual reflectors

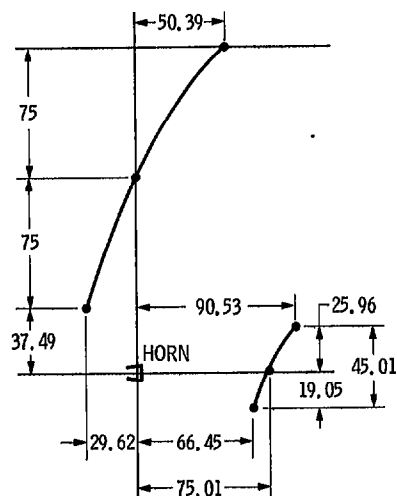


Fig. 3. Major dimensions (in cm) of the 1.5-m model

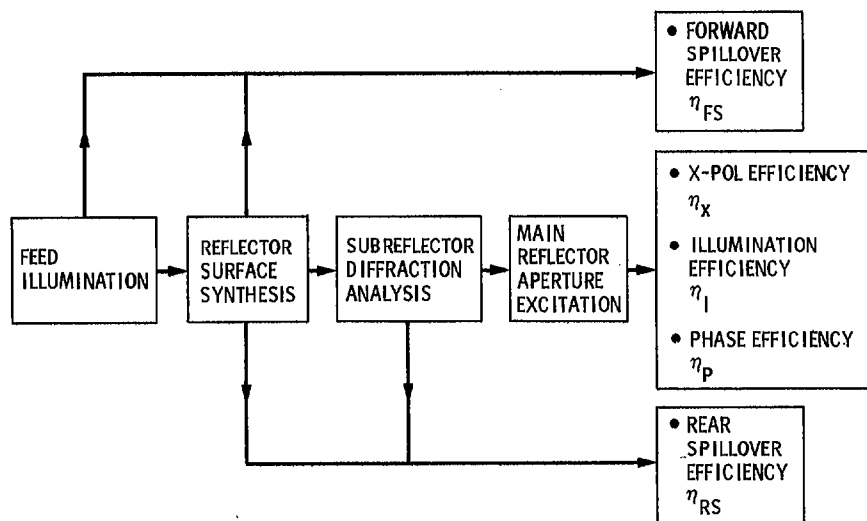


Fig. 4. Overview of reflector RF performance analysis

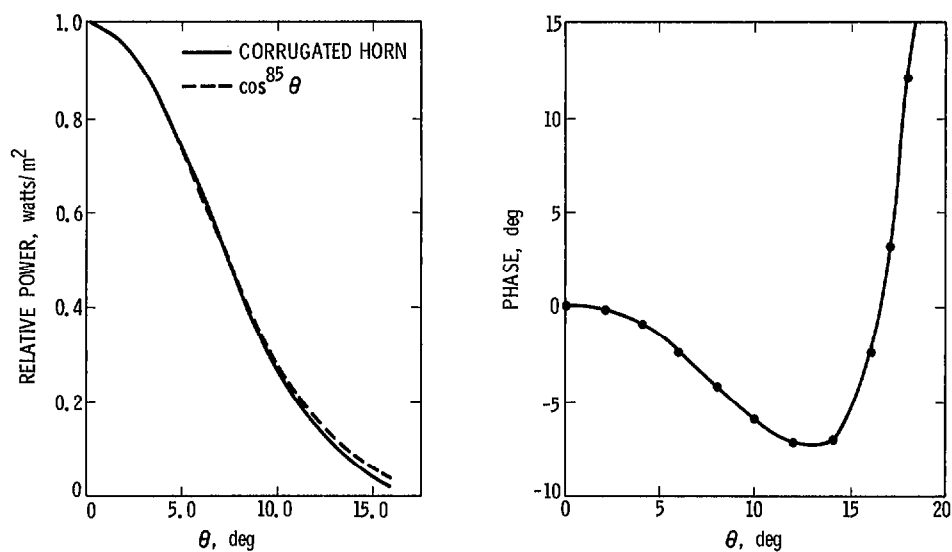


Fig. 5. Corrugated horn pattern fit by $\cos^n \theta$, (a) power patterns (b) E- and H-plane average phase of horn

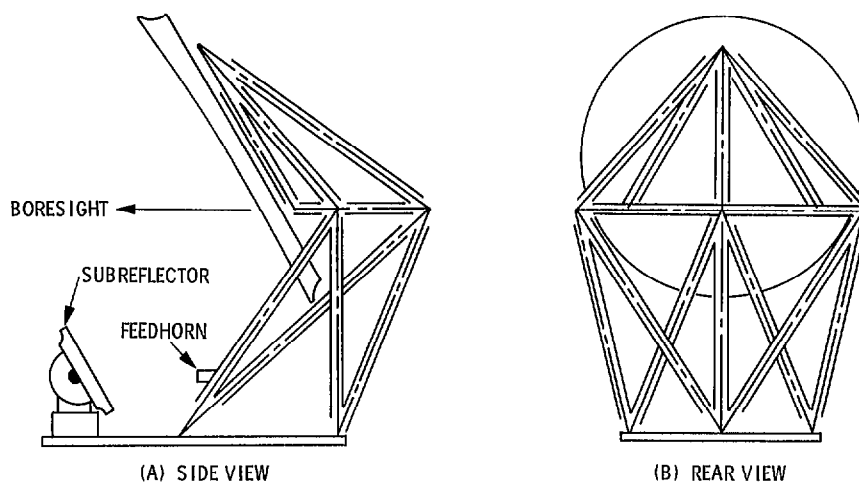


Fig. 6. 1.5-m clear aperture model and backup structure